QUALITY CONTROL AND NONDESTRUCTIVE TESTING FOR THE PREVENTION OF FAILURES IN SCIENTIFIC SATELLITES

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NASA - Goddard

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The Role of the Contractor

The primary purpose of this paper is to help inculcate in the minds of all who are engaged in the space program a greater feeling of responsibility for the production of a first-class product. You may be surprised at this statement, and some of you no doubt are saying that you already are trying your best to produce a first-class product. However, experience indicates that a large number of the components and structures and finishes going into space hardware are not first-class simply because of poor workmanship and improper material selection.

The reasons for the lack of performance of these components are primarily two in number. First, the prime contractor and the major sub contractors do not make adequate use of their own materials and processes experts during the materials-selection and specification-writing phases. These trained metallurgists, ceramists, chemists, etc. are usually asked by the design engineers to approve a major materials list which does not include many of the small items, such as fasteners, and which does not describe the detailed geometry and service environment of the parts to be made from these materials. With what little information is given him, the materials man says that, in general, this and that material is adequate or suitable. Of course, the fact that welding may make a particular aluminum alloy unsuitable for a specific application is not considered because, at the time, the method of fabrication has not been decided upon.

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The point is that many contractors do not assign materials people to the project to remain in close contact with it. In many cases it is only after a particular component fails in testing that the materials people are consulted. By that time, many thousands of dollars of man-hours have gone into the design and fabrication of the component, and the completion schedule has slipped by weeks and possibly months. Oftentimes the materials investigation reveals, for example, a design deficiency, the use of an improper heat treatment or fabrication process, an inadequate surface coating, or an unsuitable material. These costly errors could be avoided in most cases with early and continued use of qualified materials experts.

Secondly, the major contractors do not exert adequate non-destructive testing and quality control procedures over the manufacture of the components. This is especially true for those components which are procured from numerous small vendors. These small production shops, in many instances, are too small to be able to afford radiographic, fluorescent penetrant, or other nondestructive testing facilities. Consequently, many small items are delivered which have undetected flaws but which become evident after the component has failed in pressurization or vibration testing. These small concerns also may not have a quality control department which would help ensure the reliability of the product.

Accordingly, it behooves the major contractors to establish materials and processes standards and specifications for all items under their cognizance, not only those manufactured in-house, but also those procured from other manufacturers. A rigorous inspection of these incoming items also should be standard operating procedure. This inspection should be more than a visual examination by the receiving-room personnel, especially if the item did not have to meet rigid qualifications at the point of manufacture. For many materials, the oft-quoted military or federal specifications are not adequate to assure reliability in a piece of spacecraft hardware; consequently, specifications with tighter controls are required. It is understood that NASA is in the process of formulating these specifications. But in the meantime, the contractors themselves can exert greater control over the quality of the spacecraft hardware.

The first step forward in this quality improvement program should be an education and constant reminder to all those involved that the items of spacecraft hardware are not ordinary nuts and bolts, glue and wire; but that they are part of an expensive and intricate precision apparatus which will be placed in a service where minor defects may jeopardize the success of the multi-million dollar effort. It is amazing how a well-informed and interested technician with pride in his work can discover irregularities in the quality of the hardware he handles or assembles. A simple tool scratch or dent on the surface of a high-strength pressure vessel or bolt, if undetected or considered unimportant, can and, indeed, has caused catastrophic rupture. Later on a number of such detectable defects which have led to failures will be discussed. Suffice it to say here that a Rockwell hardness impression improperly placed on a high-strength (and notch sensitive) steel band between third stage and payload caused a delayed failure while the vehicle was being readied for launch.

The responsibility of the contractor in the production of a first-class product, as discussed above, is not related to any one project. The same responsibilities exist in the manned as well as in the unmanned space program. It can be said, however, that the manned program appears to have more of this contractor esprit de corps than does the unmanned program. This is undoubtedly due to the interjection of the human-life element into the reliability picture and also to the greater publicity accorded the manned shoots.

The unmanned scientific satellites are of a large variety and, therefore, of a small number of each individual type. This difference between the Mercury and the scientific satellites no doubt has much to do with the interest developed by the contractors and their employees. In the latter case, only three to five spacecraft, including engineering and prototype models, may be produced, and the program may last an average of only one to three years, depending in part upon the number of materials problems encountered. While no human life is involved in scientific satellite launches, the aim of the NASA in each case is to obtain a completely reliable spacecraft. This should be a joint goal of both the space agency and the contractor.

This discussion, although it applies in principle to all space activities, is specifically related to the prevention of failures in the unmanned scientific satellite programs which are under the sponsorship of the Goddard Space Flight Center.

Definition of a Scientific Satellite

In this discussion a scientific satellite is defined as an unmanned object placed into orbit about the earth or any heavenly body in our solar system, including the sun, which incorporates equipment or means by which scientific experiments can be carried out. In the case of the passive communications satellite, Echo I, this means consisted principally of a surface highly reflective to both radio and light waves. Although small wafer beacon transmitters were attached to the skin to aid in locating the satelloon, as it was called, Echo I had no instrumentation to gather information and send it back to earth. It was a relatively simple satellite to make from the standpoint of quality control.

Most scientific satellites do have instrumentation on board which is designed to perform experiments aimed at gathering specific information about the space environment (such as radiation belts), about our own planet (such as cloud patterns), about other planets (such as the temperature of Venus), or about our sun (such as sun spot activity). Some satellites may be developed to perform only one experiment or activity, such as Tiros, our present weather satellite; others may be equipped to conduct several experiments separately or simultaneously, such as the Orbiting Solar Observatory.

There is a great variety in the design, materials, and fabrication of these satellites. Of course, some satellites, such as Tiros may actually consist of several similar spacecrafts launched at different times. But, by and large, each satellite is an individual one which must be custom-made. It may have among its thousands of parts some which are mass-produced, off-the-shelf items, but the assembly of these, and the many specially-made items, is essentially a hand operation.

The Goddard Mission

The Goddard Space Flight Center, established in 1959, is charged with the responsibility of the investigation and exploration of space for peaceful purposes by use of unmanned scientific satellites, probes, and rockets. Its scientists conceive and design the scientific experiments, sometimes in conjunction with other scientific organizations. They usually provide the basic design of the spacecraft which will carry the experiments. When the fabrication of the spacecraft and instrumentation is left to outside contractors, the scientific personnel monitor the contract to expedite its completion, to pass judgment on necessary design or material changes, and to help coordinate the efforts of the many subcontractors, the producer of the launch vehicle, and the launch site.

The Goddard Space Flight Center, which was named after Dr. Robert H. Goddard, American pioneer in rocketry, also has considerable fabrication and testing facilities of its own. These are used primarily for in-house manufacture of research apparatus and development models of experimental equipment. However, the Center has also built, integrated, and tested a few satellites itself.

Another very important function of the center's is that of operating the world-wide tracking and communications network stations which trace the flight of the satellites, and which accumulate and reduce the data they develop.

Goddard is one of the few installations in the world capable of conducting a full-range space-science experimentation program -- from theory, through experiment design and construction, satellite fabrication and testing, rocket launch, tracking, data acquisition, and data reduction.

Besides its efforts in the study of weather and world-wide communications, the Goddard Center has pioneered the study of cislunar space, that space which lies between the earth and the moon, for the benefit of our man-in-space Mercury, Gemini, and Apollo programs. These studies detected the presence, the intensities, and the extent of the radiation belts surrounding the Earth. Although the emphasis on our manned space program has eclipsed, in a way, our unmanned program, it should be pointed out that our scientific satellites and probes remain our most important means, at the moment, of exploring our solar system. And, though they do not get the newspaper and television coverage accorded our manned shots, the conception, design, and fabrication of the unmanned scientific satellites continue as fast as economics and the state of the art will allow.

Need for Reliability

Every failure of one of these scientific satellites in achieving its mission is an extremely costly affair in dollars and time. Hopefully, even if a satellite does fail in its mission, we do learn something which is of value in a subsequent attempt. However, the amount of money involved in the launch attempt of one of these satellites, including the cost of launch vehicle, runs into the millions of dollars. Accordingly, every attempt must be made to obtain a reliability as near to 100 per cent as is practical.

The demand for levels of quality is almost unbelievable in the space industry; however, it is necessary. For example, there may be more than 300,000 parts in any one satellite launch unit, i.e. launch vehicle and satellite. Even if a reliability of 99.99% is maintained, it has been stated that only three launches in 100 will function perfectly in all respects.

In the Mercury space program, all spacecraft capsules were essentially similar in design and materials of construction. Consequently, reliability was able to improve with each orbital flight as a result of natural development and the suggestions of the astronauts. In addition, one could say that because of the human life involved in the program, greater quality control was exercised consciously and unconsciously over all systems than might be exercised in the case of the unmanned program. Every person working on the Mercury components had a personal interest in doing a good job.

The same need of quality also exists in the scientific satellite program, because we cannot practically return to Earth a malfunctioning spacecraft to correct its defective component. In the case of such a malfunction, we generally can only guess as to its cause. For example, Syncom I, our intended synchronous-orbiting communications satellite which was launched in February of this year, became lost several hours after launch. Its power failed completely for some reason still not definitely established.

The Bell Telephone Company's Telstar I active communications satellite also became mute after about four months operation. In this case, however, the cause of the trouble was determined by a reconstruction in the laboratory of the satellite's electronics, which duplicated the malfunction and identified the defective unit as a transistor in the command decoder. Corrective action was possible in this case because of redundant systems.

Another, more subtle, reason why high quality is desired in scientific satellite hardware is simply that we want to be sure that the information the satellite gathers is correct. If, for instance, an optical lens on a piece of equipment has an impurity in it which, with time and exposure to ultra-violet, electronics, or other radiation causes a change in transmissivity, the data acquired through that lens could possibly be in error. Nondestructive tests for such cases are generally non-existent, primarily because it is almost impossible to know before hand and in exact detail all the environmental conditions that each part of the spacecraft will see. We do have some idea of these environments, and additional knowledge about them is constantly being acquired. The nondestructive testing state-of-the-art need only keep up with the space environment state-of-knowledge.

How to Achieve Better Reliability

How can the reliability of the satellite components be increased? Well, certainly better assurance of good quality is obtained when all items installed on the spacecraft have been previously adequately examined, as opposed to the case where the lot from which they were selected was only spot checked by examination of a few randomly-selected samples. In the fabrication of space-flight hardware, where 100% reliability is desired, one would think that all items would be examined 100%. This is not the case at the moment in the manufacture of scientific satellites. Many parts are standard stock items which have been produced primarily for use in an earthly environment. In many instances, the people responsible for the selection of materials are not aware of the effects the space environment may have on the materials which might render them useless or even harmful to the spacecraft's mission. As an example, many contractors are still using cadmium-plated hardware in satellites designed for vacua of 10^{-9} torr or lower, despite the Goddard directive not to use cadmium. This is one reason why subsystems and each fully-integrated spacecraft must undergo a vacuum exposure test prior to qualification.

Another means of increasing the reliability of the satellites would be the establishment of an industry-wide set of material and component specifications which are specially prepared for spacecraft hardware. Up to now, NASA does not have such specifications and has, therefore, relied on individual vendors standards, some of which are less elaborate than others. In many instances, even vendor specifications do not exist because it is assumed that the subject hardware will serve adequately since it, or another similar to it, has done so in other applications here on Earth. NASA is presently preparing design criteria which hopefully will serve both government and industry designers as standards for the selection of testing techniques and materials with the aim of increasing both the quality and the reliability of all satellite components.

The nondestructive testing industry itself could do much to improve the situation by taking a greater interest in the problem. It appears that up to the present time the spacecraft manufacturers have held the initiative in pushing for new and improved nondestructive testing techniques, principally because they are closer to the problems. These manufacturers, whether they be government or industry, would certainly welcome the testing industry's assistance, especially if the manufacturer is new in the business.

Problems of Satellite Variety

Earlier some of the many satellites for which Goddard is responsible were mentioned. Each one is quite different from the other and, therefore, must be custom-made. This kind of fabrication is not conducive to good quality control because, in most cases, the number of items is too small to warrant a large expenditure for expensive nondestructive testing equipment or for a staff of quality control engineers. The contractor did not include an adequate estimate for such work in his proposal in many cases because, for one reason, he did not know all of the problems he might encounter. Consequently, as fabrication and integration proceeds additional money must be granted for material testing and development as is indicated by component failures.

Also, the variety of contractors building the satellite hardware is almost as great as the variety of satellites themselves. Some contractors have been in the aerospace business for a long time; others have formed aerospace divisions in their diversification process; still others have just recently sprung into existence. The amount of experience in the business of these companies varies greatly. Consequently, problems encountered by one manufacturer are invariably encountered by another. One of the principal unofficial functions of the Goddard liaison engineers is that of passing information developed by one contractor on NASA funds to another so that the second might avoid the pitfalls of the first. Some of the information developed by contractors, especially on the subject of outgassing characteristics of materials in vacuum, is used by them to select the materials for the spacecraft systems, and then this information may lie unpublished in company files, requiring another contractor contemplating use of the same material, to run his own outgassing studies. There is certainly a need for all this information to be funnelled to a single repository from which it can be made available to others.

Unfortunately, many of the materials or processing techniques that must be used on satellites at this point are proprietary in nature, and the relevant company may not willingly release information concerning its details of manufacture or even of testing. Such is the case with some thermal control coatings and solidfilm lubricants.

The variety of spacecraft problems encountered is not only a result of the variety of materials and devices occasioned by the variety of satellites, but it is also a result of the variety of space environments the spacecrafts see. Some satellites orbit near the Earth, within a hundred or two hundred miles in a circular fashion. In this case, the radiation exposure may vary, but the vacuum would be quite constant. Other satellites may be in circular orbits at much higher altitudes, where both the radiation and vacuum and other effects are different than the first. Still other satellites may be placed into elliptical orbits with apogees thousands of miles high and perigees only a hundred or so miles high. In such cases, all space conditions are everchanging. Accordingly, it is logical that some materials or devices may be suitable for some spacecraft but not for others.

Some idea of the variety of spacecraft shapes that are under Goddard's sponsorship may be had from a study of Figures 1 and 2. Pictured in the artist's drawing of Figure 1 are those satellites which have already been launched. The largest of these is the 100 ft. dia. Echo I satelloon passive communications satellite which has been orbiting for more than three years. Most of these satellites, like the Explorer series, have been used to study the radiation and magnetic fields surrounding Earth. As can be seen, there was some variety even within this series of spacecraft. The Tiros series were essentially all similar in outward appearance and were and are used, of course, to study the Earth's cloud cover. The Orbiting Solar Observatory(OSO), which was launched about a year ago, carried several experiments on board, all aimed at either studying some aspect of the sun or else the effect of its radiation on coatings.

In Figure 2 are pictured satellites which, in general, have not yet been launched. One of them, Syncom IA, was launched but, as was mentioned earlier, its power supply failed to function. A back-up Syncom satellite, IB, has been launched after some changes, and is functioning successfully. Also pictured is Relay I which was successfully orbited last December and is an active communications satellite at a much lower altitude that the 22,000 mile orbit of Syncom. Relay has had some malfunctions in its brief lifetime, but is still operating to some degree. OAO, the 3,200 lb. Orbiting Astronomical Observatory is probably the largest shown in this figure with the exception of the advanced satellon, Rebound. The Rebound satellite, with a diameter of 135 ft, is an advanced Echo passive communications satellite. It is fabricated from a laminated aluminum-mylar-aluminum material rather than the very thin aluminized mylar used for Echo. This heavier material is designed to rigidize the structure in orbit, and thereby maintain its shape over a longer period. Fabrication of this laminate has presented quality control problems which will be discussed later. Three such satellites, each weighing 600 lb. are to be orbited from the same launch vehicle but uniformly spaced about the Earth in a 1500 mile high circular orbit. Nimbus is an advanced weather satellite, and OGO is the Orbiting Geophysical Observatory that can carry 50 different experiments on a single mission.

Factors Affecting Quality Control

In this variety of satellite spacecrafts there are represented many different materials in many diverse forms, produced by practically every fabrication method known to man. Metal alloys, plastics, rubbers, glasses, solid state devices, ceramic and chemical coatings, gases, and liquids - all may be present on a single spacecraft. These and other materials are produced by casting, forging, extrusion, rolling, stamping, welding, brazing, soldering, riveting, adhesive bonding and perhaps other processes as well. They are electroplated, flame sprayed, painted, chemical milled, vapor deposited, heat treated, high and low temperature cured, sintered, and irradiated.

With this variety of materials, processes, and treatments all to be quality controlled for optimum reliability, it is understandable that the task is a formidable one. As pointed out earlier, the small numbers of items required in some cases negates against good quality control. Also, the hostile and little known space environment in which these many materials and devices will operate make quality control difficult. What may be a good quality device for an earth-bound application, may not function reliably or at all in space.

We attempt to determine such possible problems by environmental tests in vacuum chambers under simulated solar energy conditions. Such tests can be termed non-destructive, if the device functions satisfactorily. However, at best the vacuua we can achieve do not approach that of altitudes of more than 500 miles, and the simulated solar energy is just a close approximation of the actual sun's spectrum. In addition, the combined conditions of ultraviolet, electron, proton, and other radiations, as well as micrometeoric bombardment, cannot be duplicated here on earth.

Another reason why quality control is sometimes difficult to achieve, especially in instrument packages, is that the state-of-the-art in sensors, electronics packaging, solar cells, and others is advancing very rapidly in many small laboratories, and this advance is leading quality control by some margin. The reason for this is that these small organizations may not have any quality control group or adequate testing facilities. Their developmental problems are known only to themselves. Sometimes they cannot identify the problem area and malfunctions show up only after assembly of the integrated instrument.

However, it should be pointed out that a lot of non-destructive testing is being employed in satellite manufacture, especially by the larger contractors. These tests include most of the convertional techniques, such as radiography, magnetic and fluorescent particle, ultrasonic, strain gaging and strain sensitive coatings, and visual inspection with various aids. These are generally used on structural parts of the spacecraft at various stages of fabrication and testing. Other non-destructive tests include electrical performance tests of completed electronic modules, transistors, or solar cell arrays. These tests may indicate whether a part is defective or not, but oftentimes they cannot pinpoint the defective area.

Obviously, in satellite manufacture we are dealing with some very small, but critical, items. A power transistor may be only a fraction of an inch in size, and consequently difficult to examine, but it may jeopardize the success of a several million-dollar mission. Frequently, it is cheaper to discard a defective device rather than attempt to repair it. To increase reliability in the electronics systems, most satellites are equipped with redundant systems. Hopefully, some day this technique will no longer be necessary.

<u>Typical Problem Areas</u>

The following are some examples of areas where problems have developed which could have been prevented by more adequate quality control and non-destructive testing. It is true in some cases that the significance of a condition to good performance was not known until after failure occurred. In the case of the attempt to launch a second Echo satellite, motion pictures taken by a camera recovered from the launch vehicle showed that the balloon ripped open on inflation. In an attempt to determine why, the aluminized mylar and other balloon materials were subsequently examined. Briefly, what the study showed was that the plastic films generally do have orientation stresses residual from the manufacturing process. These residual stresses reduce the ability of the plastic to take the rapid inflation stresses without tearing. At low inflation rates, they fair better; so one approach is to regulate the rate of sublimation of the inflating chemical.

Because the 0.5 mil thin aluminized mylar material used on Echo I was too flimsy to maintain the balloon in spherical shape over long periods of time, the more rigid laminate of 0.18 mil aluminum foil to 0.35 mil mylar to aluminum foil was specified for Echo II. In static inflation tests of full-size balloons at Lakehurst, New Jersey, ruptures occurred at lower-than-calculated pressures. Figure 3 shows one of these 135 foot diameter balloons during the inflation tests. Examinations of the failed balloons disclosed a fold defect in the balloon material, shown in Figure 4. After the aluminum foil had been adhesively bonded to one side of the mylar, processing rolls introduced numerous narrow folds of various lengths just prior to the bonding of the aluminum foil on the opposite side. Inspection following processing was inadequate to detect these folds shown in cross-section in Figure 5. Upon inflation of the balloon, the single thickness of aluminum foil at these defects was inadequate to sustain the load. At these points, consequently, the aluminum ruptured and induced a shock or impact load on the remaining foil-mylar laminate which caused the tupture of the balloons.

Since many of the experiments on board the satellites, as well as star-trackers and sensors, may incorporate lens systems open to the radiations in space, these lenses must be checked for fluorescence under anticipated electron bombardment if such fluorescence would mask the incident energy and give erroneous results. Many contractors specify lens materials without checking their fluorescence tendencies. Consequently, some lens materials had to be rejected for this reason after fabrication.

Figure 6 pictures a 7075-T6 aluminum panel from the OSO spacecraft currently being built. This panel is typical of some which developed cracking at the inside bend radius during vibration testing as seen in Figure 7. A check of the panels at the spacecraft contractor disclosed that some were not heat treated, including those which developed cracking. The panel forming was performed by one vendor, the heat treatment by another. No rigid inspection was exercised on these panels at any point during manufacture.

In Figure 8 is pictured a section of a pressure welded titanium alloy bottle that will contain nitrogen gas under pressure on the OSO for attitude and spin control. This one was tested to destruction and failed at approximately 7800 psig, far above the 3000 psig pressure it will hold. However, the test was conducted with water at room temperature, whereas the bottle may see -50°F or less in space. It is known how a drop in test temperature of 100°F or so can change a ductile material into a brittle one. In addition, small defects in the pressure-weld seam may gradually grow under the stress of the internal pressure until it reaches a size large enough to initiate a catastrophic explosion-like rupture long before the intended one-year service has been reached. Besides a lack of consideration of brittle fracture possibilities, forgings from two different manufactures are sometimes welded together in the fabrication of these bottles.

Most satellites have batteries for power to supplement a solar cell system. Shown in Figure 9 is a typical zinc-silver cell. The case is injection molded polystyrene. Several such cases cracked open in the laboratory some time after the electrolyte was added. When similar cases were observed through the polariscope, residual strain patterns were visible, as can be seen in Figure 10. These cases were not annealed after molding, and the manufacturer increased the capacity of his battery by forcing more plates into the same size case. These two conditions contributed to the cause of the failures.

It has been known for many years now that certain metals, such as electroplates of zinc, tin, and cadmium, grow thin metal whiskers. When these platings were used on low-voltage electronic components, they sometimes grew whiskers which created electrical short circuits. Many spacecraft component systems are fitted with electrical connectors, like the type shown in Figure 11. This multi-contact connector has a brass shell which is plated over with cadmium. A cross-section of this connector in the mated condition is pictured in Figure 12. Here a space can be seen between the plastic inserts of both connector halves into which metal whiskers can grow and possibly make contact with one or more of the pins. Although the possibility of metal whisker growth being a problem in this case is remote, it is one which can be eliminated by the use of connectors not plated with these metals, or by the use of an internal gasket to fill the void. In one case, a spacecraft included a hundred or more of these cadmium-plated connectors, already potted or fastened in place, when this fact became known at Goddard.

Nickel-cadmium batteries used on board some spacecraft in general are a stock item which are used in many earth-bound applications. Consequently, they are not manufactured especially for spacecraft use and have been a continued source of trouble. In one instance, after vibration testing the voltage of the batteries was found to be degraded. The battery was radiographed prior to destructive examination. The radiograph showed that the nickel oxide paste of the positive electrode developed crazing cracks during vibration which accounted for the voltage drop. The cracking was caused by the loose condition of the cells in the battery case. This was corrected by additional crimps in the case.

Figure 13 shows the top sides of two solar cells. The solder contact strip along the top edges and the solder collector grids were a source of trouble in that occasionally they would peel during thermal cycling. This condition also occurred on the reverse side of the cell which is solder covered. The lack of bond strength between the silicon and a vapor deposited layer of titanium and silver (over which the solder is placed) was found to be the result of poor cleaning of the sandblasted silicon surface. Now chemical etching procedures are used to clean the surface prior to the vapor deposition.

Most all active satellites have tape recorders on board, and they too are not free from problems. Many recorder heads are fully fabricated only to be rejected on final check-out. A study of the failures included radiographic inspection, as shown in Figure 14, and dissection. This investigation disclosed that a room temperature cure was being given to the epoxy-polystyrene potting material which, when exposed to the thermal vacuum test, probably developed additional cure and shrinkage enough to rupture one or more of the 2-mil diameter wires of the core windings. It was also noted that air was entrapped in the recorder head during the potting operation which no doubt added to the stressing developed on the wire.

On the OGO satellite, an infra-red horizon scanner moves through a 45° arc on positor flexure pivots, such as the one pictured in Figure 15. This pivot assembly consists of glass-epoxy laminate curved mounting sections which pivot through the copper-beryllium alloy springs. The springs are only .002 inch thick, by .036 inch wide, by 1-1/2 inch long and are currently made of alloy 190 in the extra hard heat treated condition. As shown in the slide, the springs fracture during vibration testing of the scanner assembly. This device has developed failures for some time. Alloy 25 was originally used in the springs, but they that had a poor surface condition and rough edges which caused failures. Other springs were susceptible to stress corrosion cracking caused by ammonium hydroxide in the solder flux that was used. Care was not taken in the application of the flux and some of it found its way to the spring center sections which were not cleaned off, an example of poor quality control. Now the springs are examined stereoscopically for surface condition. The Kodak photo-resist method is used to trim the springs to size and eliminate the bad edge condition, and then the springs are electropolished to a smoothness of less than 5 microinches.

Figure 16 shows a transistor, such as that used on our Relay satellite. It will be recalled that this satellite functioned sporadically soon after launch and this transistor was suspected. A switch to a redundant circuit, which by-passed the defective transistor, permitted successful operation. In the manufacture of this hermetically sealed transistor, dry air with dew-point below -50°F is introduced into the can. However, sporadic operation of the transistors was noted during laboratory tests, especially during thermal cycling. This condition was traced to the existence of leaks in the cans which permitted moisture to enter. Condensation at low temperatures then occurred across the circular contacts on the interior of the can seen in Figure 17. At higher temperatures, the condensed moisture film evaporated and thus permitted the sporadic operation.

Another hermetically sealed transistor developed malfunction after a storage test at 200°C for 168 hours. After vibration testing it returned to normal operation. Subsequent opening of this unit disclosed a loose flake of solder which was believed to have caused the trouble. The explanation advanced is that the solder flake had caused a high-resistance short between the base and collector. Subsequent vibration testing then loosened the flake from its shorted position and returned the transistor to normal operation. A similar examination of 16 such transistors after testing revealed that three had loose solder flakes. Better quality control is certainly required in this case.

These are but a very few of the problem areas which are encountered in scientific satellite manufacture. They represent areas where the contractors have not exercised adequate inspection and quality control, primarily because the government has been paying all of their costs. Recent contract regulations are aimed at penalizing contractors when cost over-runs are permitted to occur. Hopefully now, companies engaged in new NASA contracts will make better utilization of their qualified materials and processes personnel at an early and all stages of the contract.

Conclusion

This has been an attempt to describe some of the problems associated with the manufacture of scientific satellites, and how the variety of materials and requirements compound these problems. Quality control is difficult to maintain because of the lack of adequate specifications. And specifications are difficult to write because of a lack of details concerning the service requirements. The requirements cannot be exactly pinpointed because environmental conditions vary with the spacecrafts' orbital altitude and orbit geometry.

One definition of quality control states that it is a concept which requires that every product be checked against established standards to make sure that nothing defective reaches the consumer. Obviously, as just pointed out, adequate standards are not presently available. Does that mean there should be no quality control? Definitely not!

We can practice quality control based upon existing standards, even though not adequate, and make improvements as new standards develop. However, quality control can also be inculcated on every worker's mind, every day, in every American plant until Americans again become proud of their handiwork.

An apropos conclusion to the foregoing are the words of Raymond Loewy, famous industrial designer: "America is engaged in a fight to maintain leadership, not only in space, but also in trade, training, goods, and taste. It is a fight in which our country looses a little each time any one of us lets his standards fall".

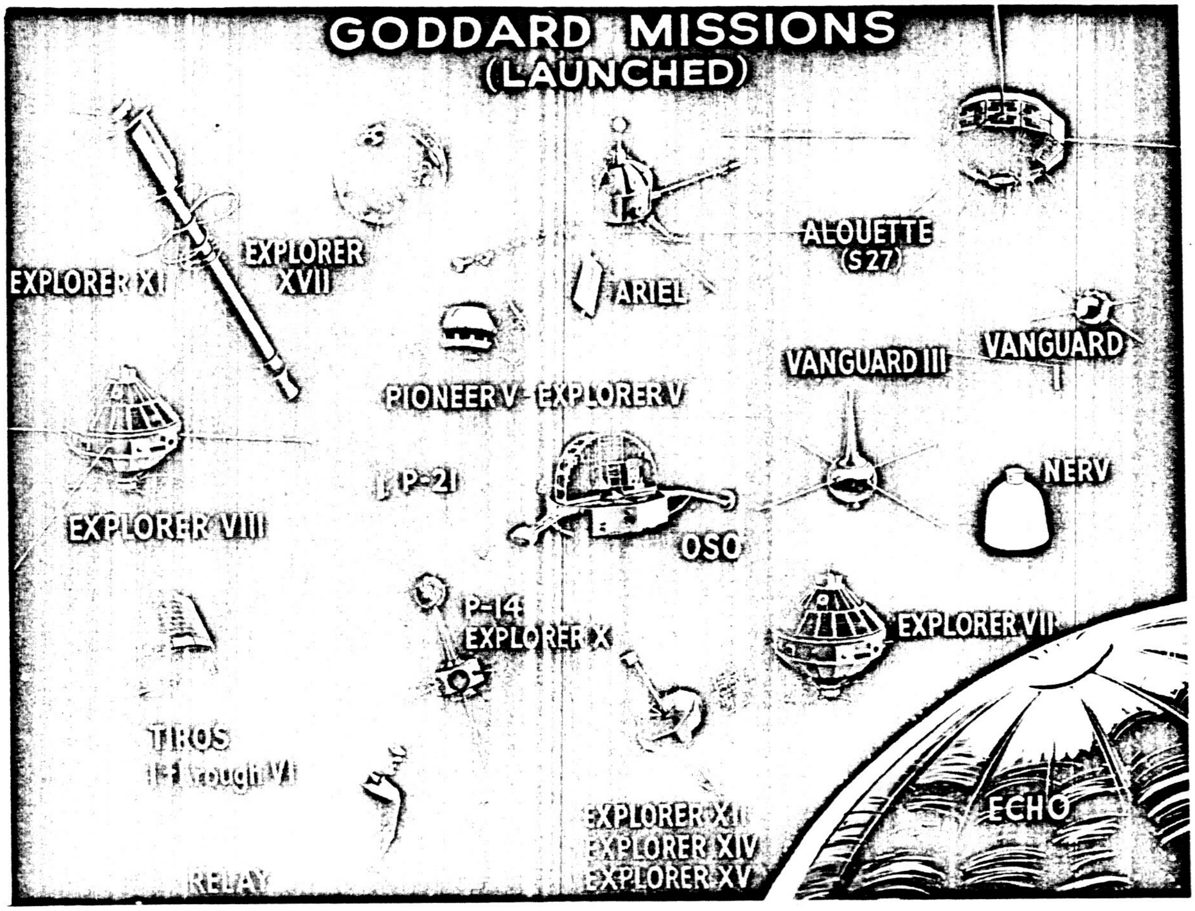

Figure 1. Goddard Scientific Satellites Which Have Already Been Launched.

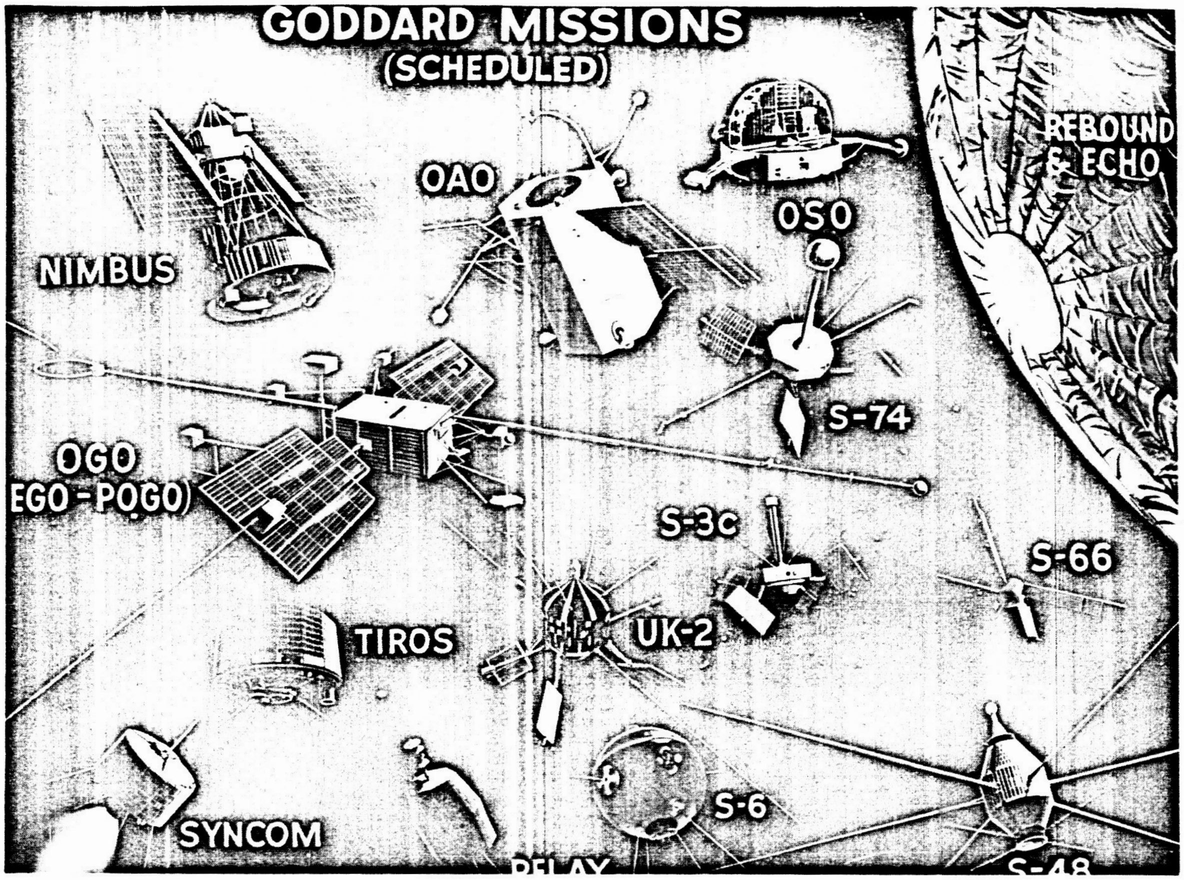

Figure 2. Goddard Scientific Satellites Recently Launched or Scheduled for the Future.

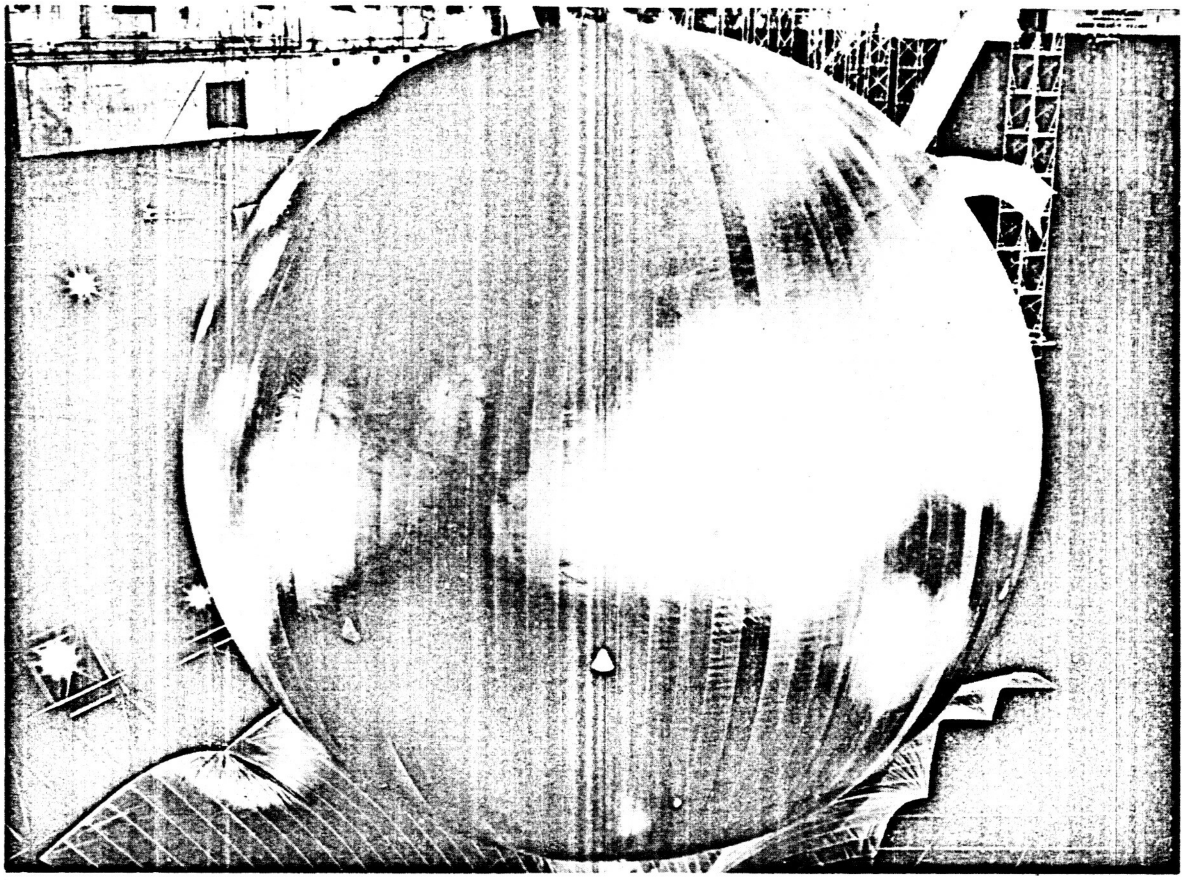

Figure 3. Echo II Full-Size Model During Static Inflation Test.

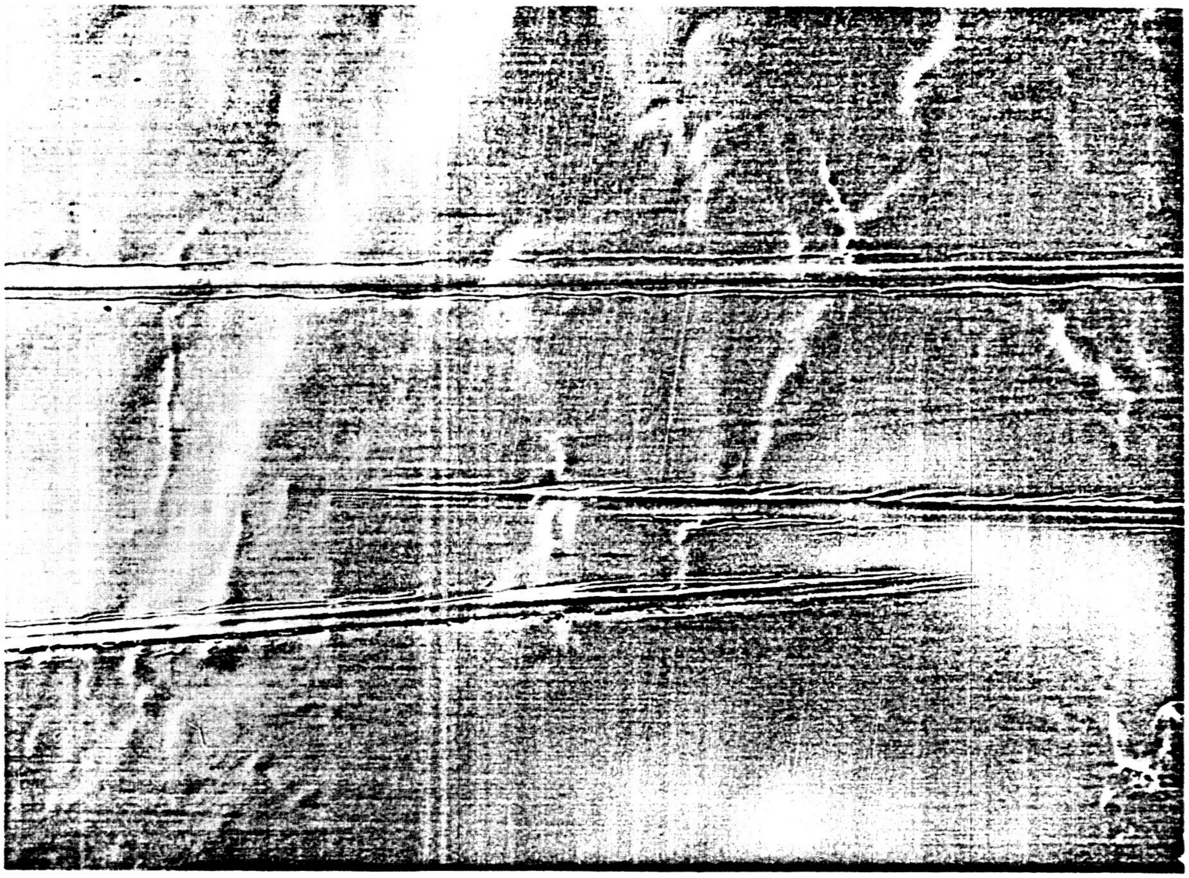

Figure 4. Fold Defects in Echo II Laminate Introduced During Processing.

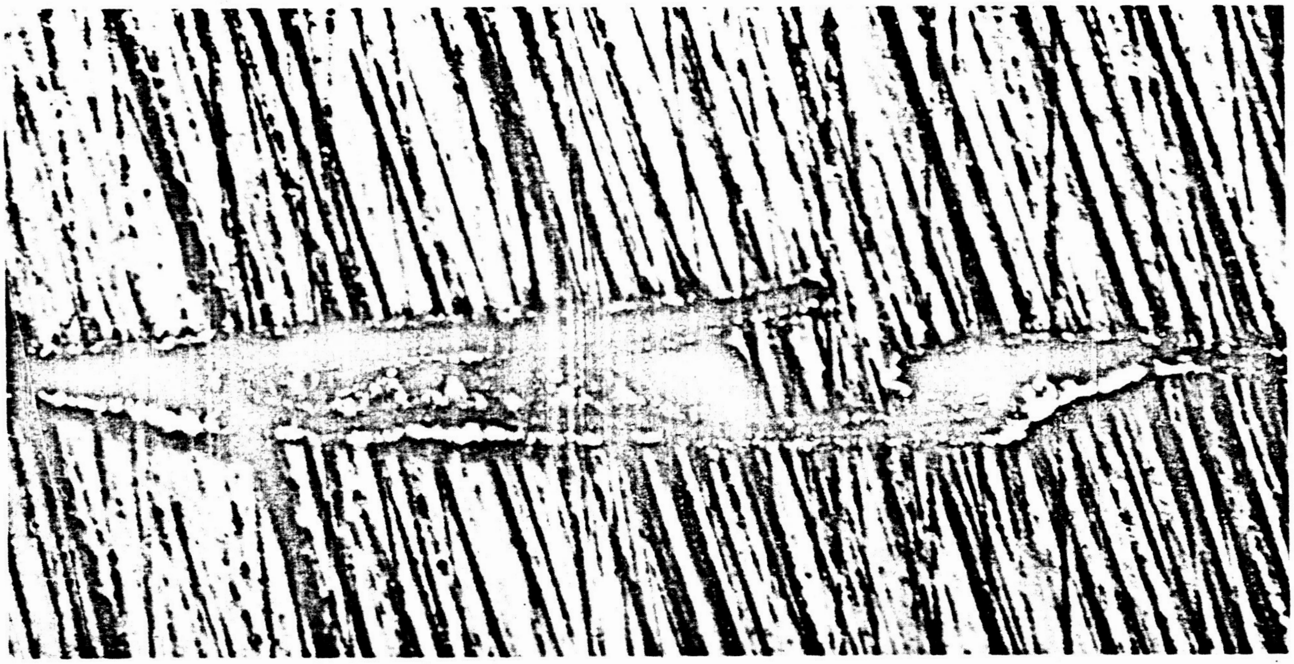

Figure 5. Cross-Section of Fold Defect in Echo II Laminate, Imbedded in Mounting.

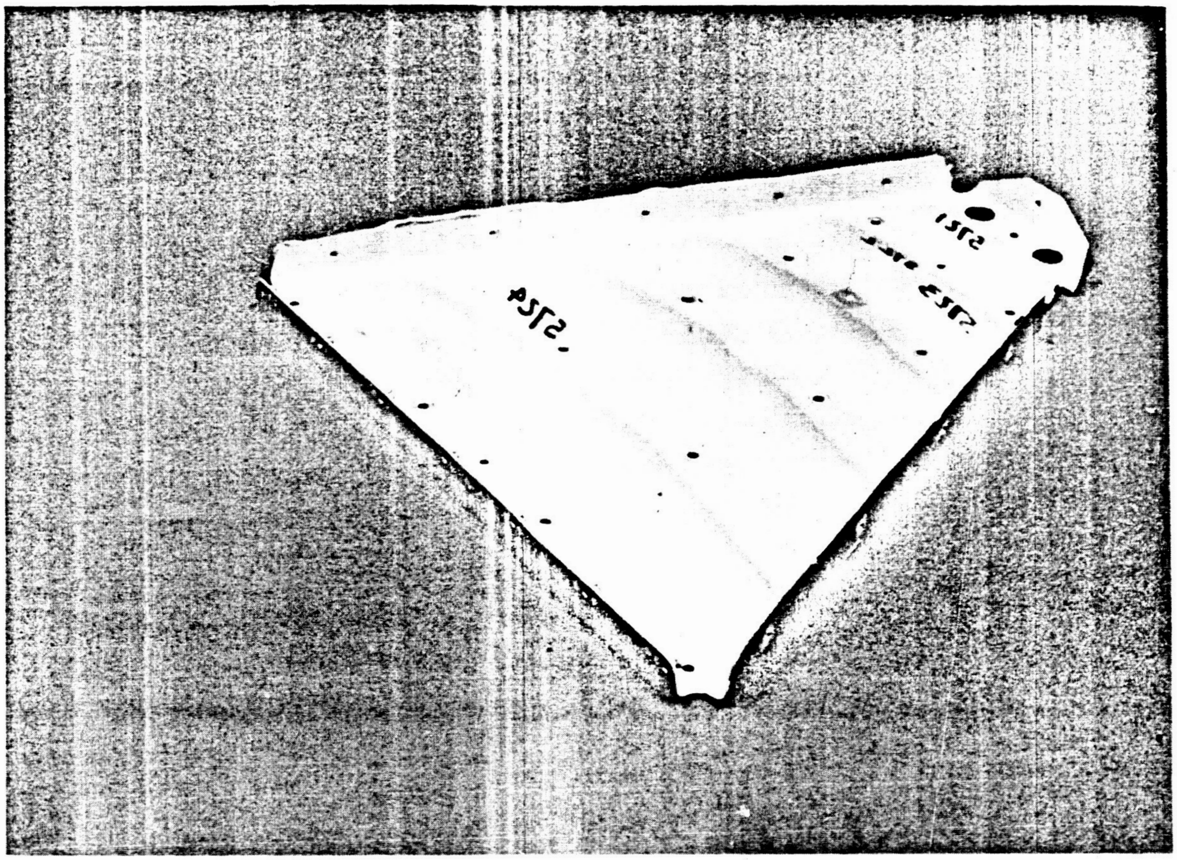

Figure 6. Deck Panel Section From OSO Space-Craft Which Developed Cracks at 90° Bends During Vibration Testing.

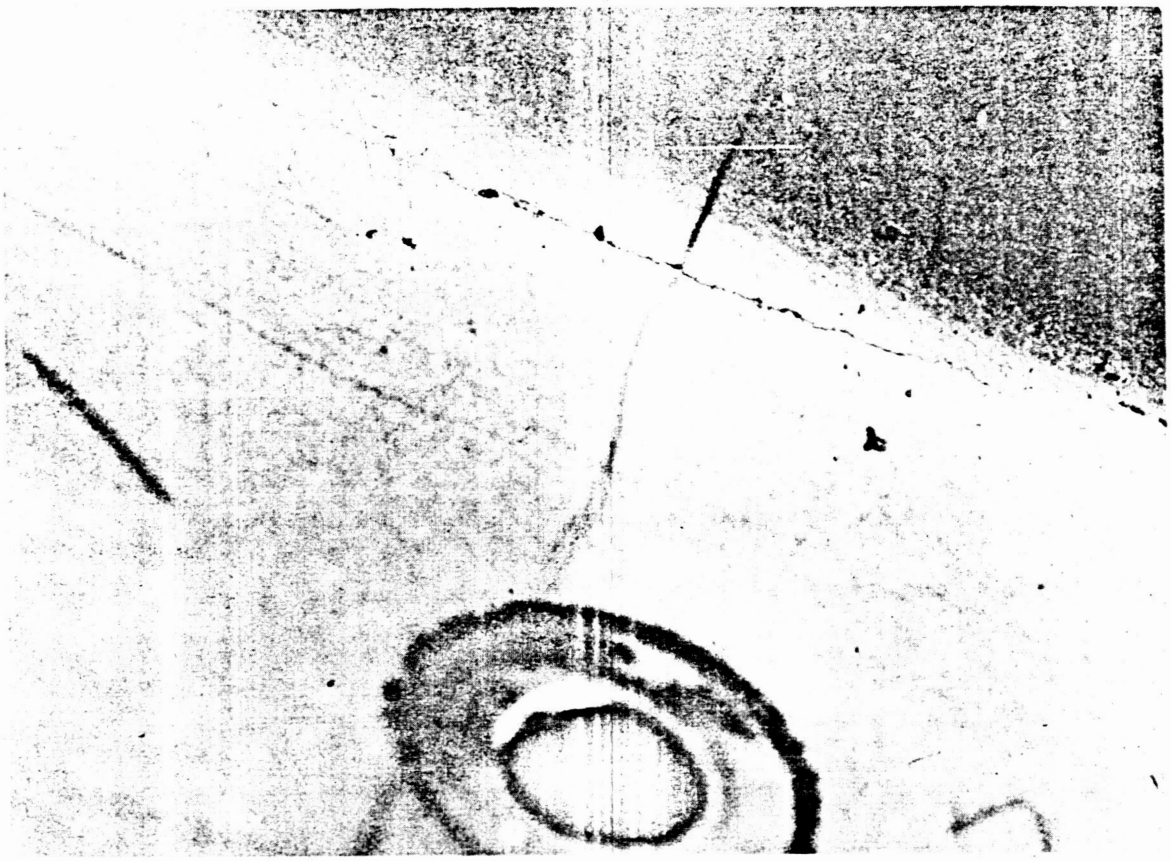

Figure 7. Close-Up of Cracking in OSO Deck Panel Pictured in Figure 6.

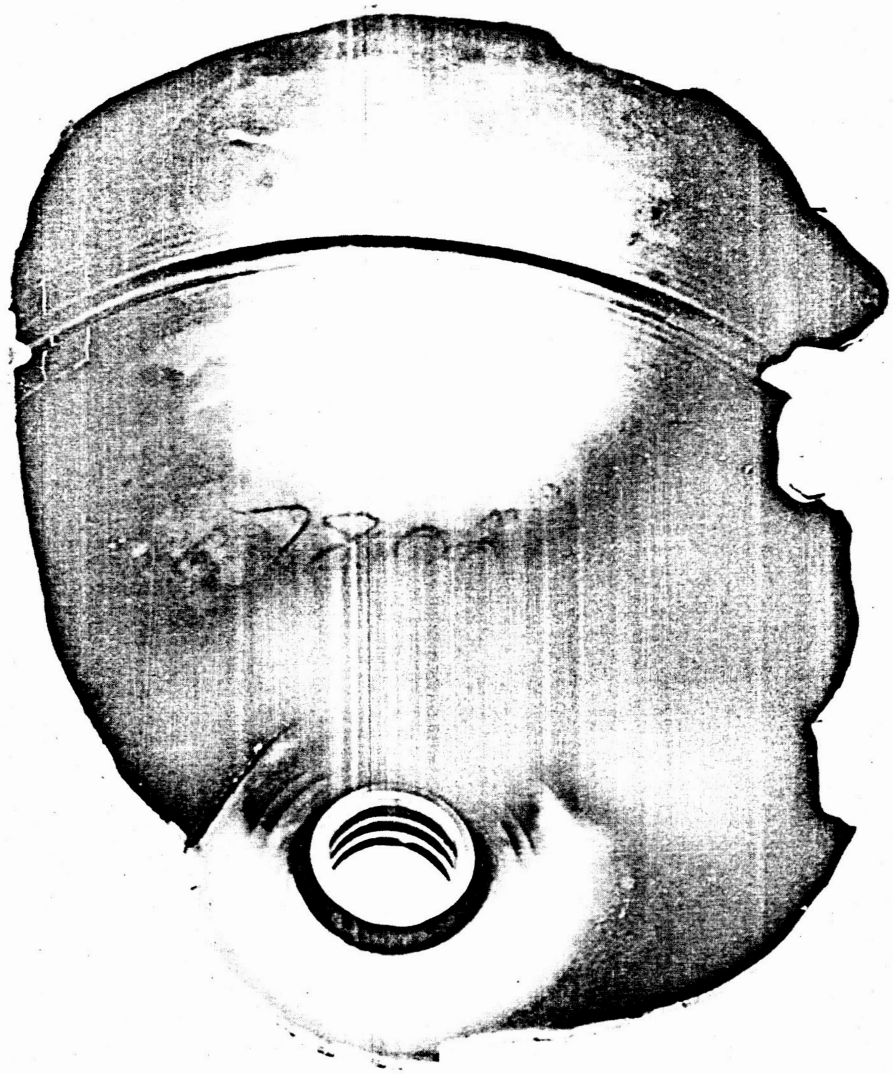

Figure 8. Section of Burst-Tested Titanium Alloy Gas Bottle Manufactured by Pressure Welding.

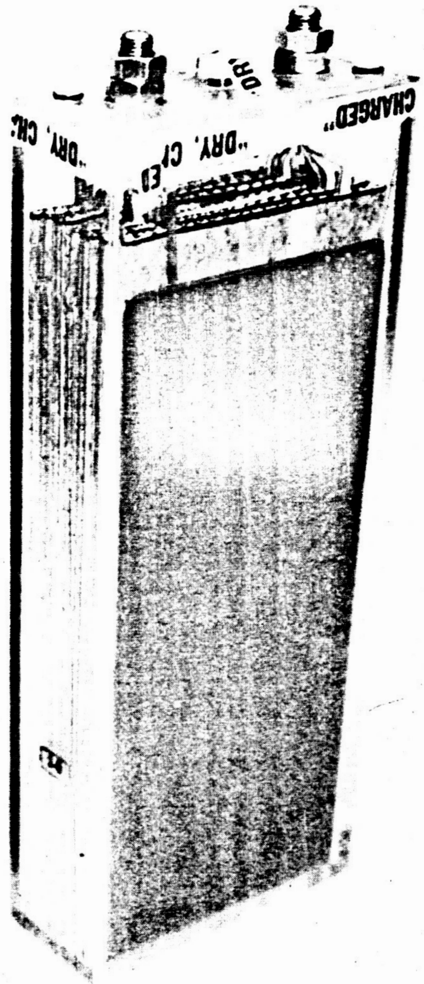

Figure 9. Zinc-Silver Battery With Injection Molded Polystyrene Case.

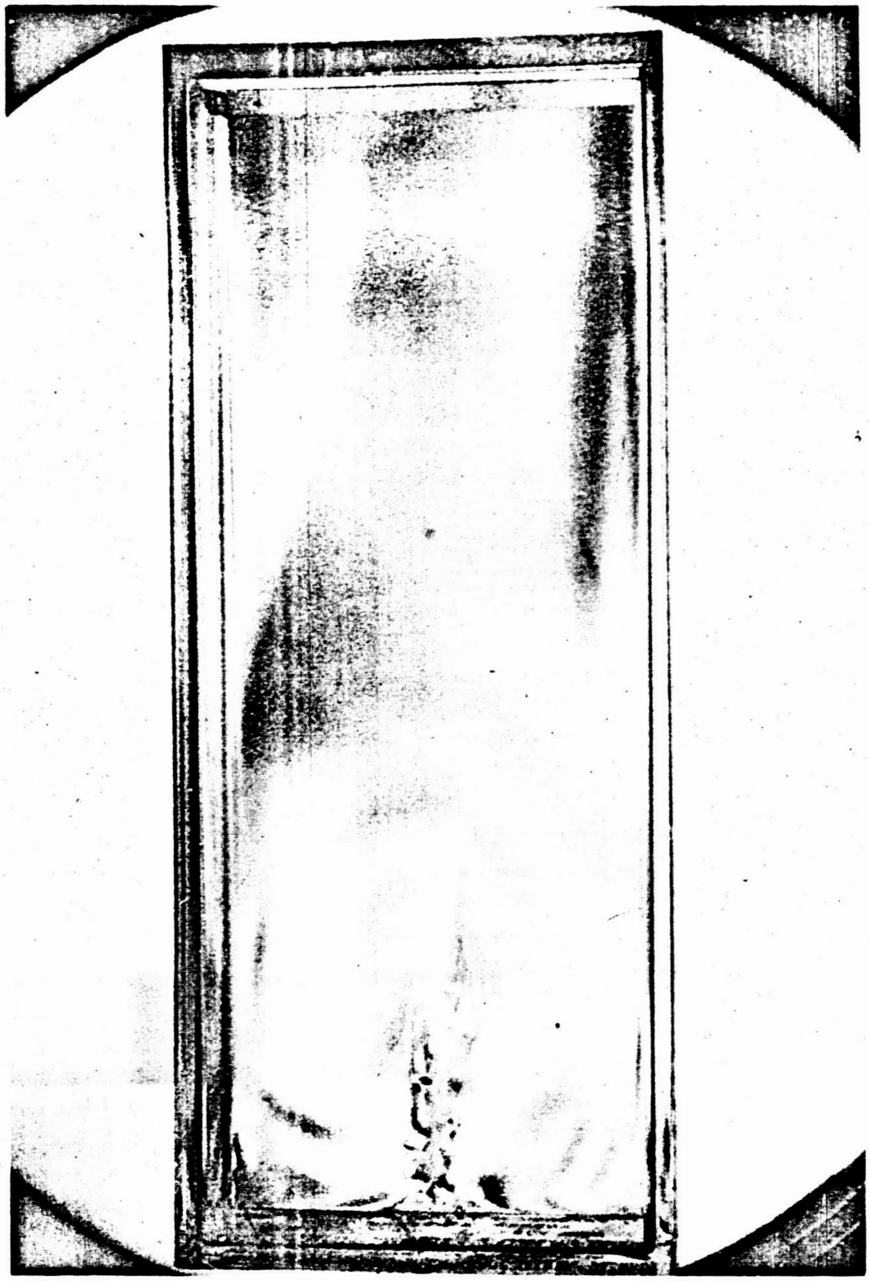

Figure 10. View of Polystyrene Battery Case as Seen Through Polariscope Showing Residual Stress Pattern.

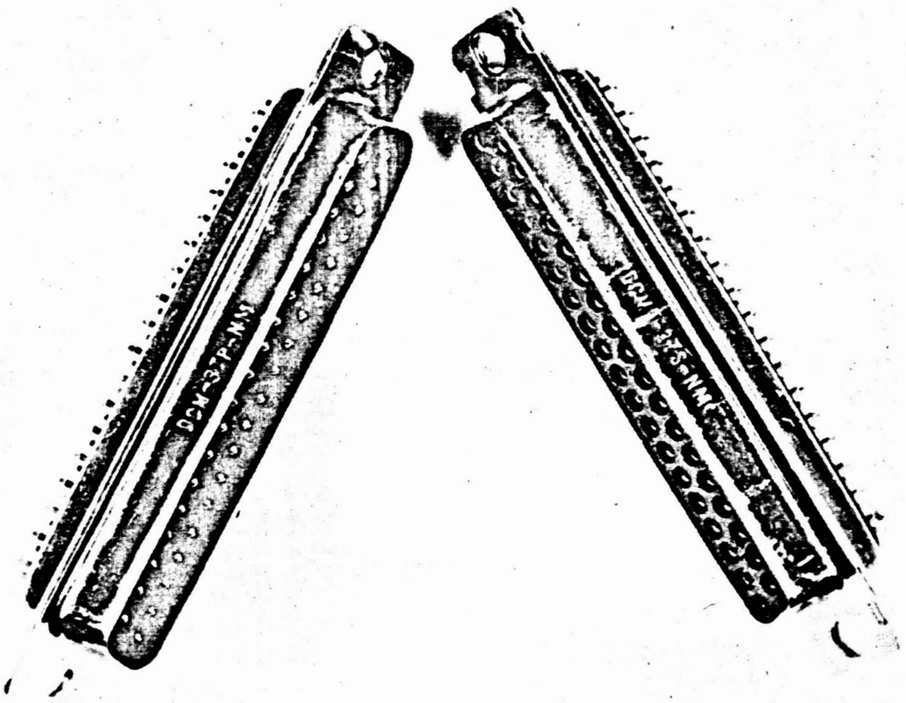

Figure 11. Typical Cadmium-Plated Electrical Connector Used on Spacecraft.

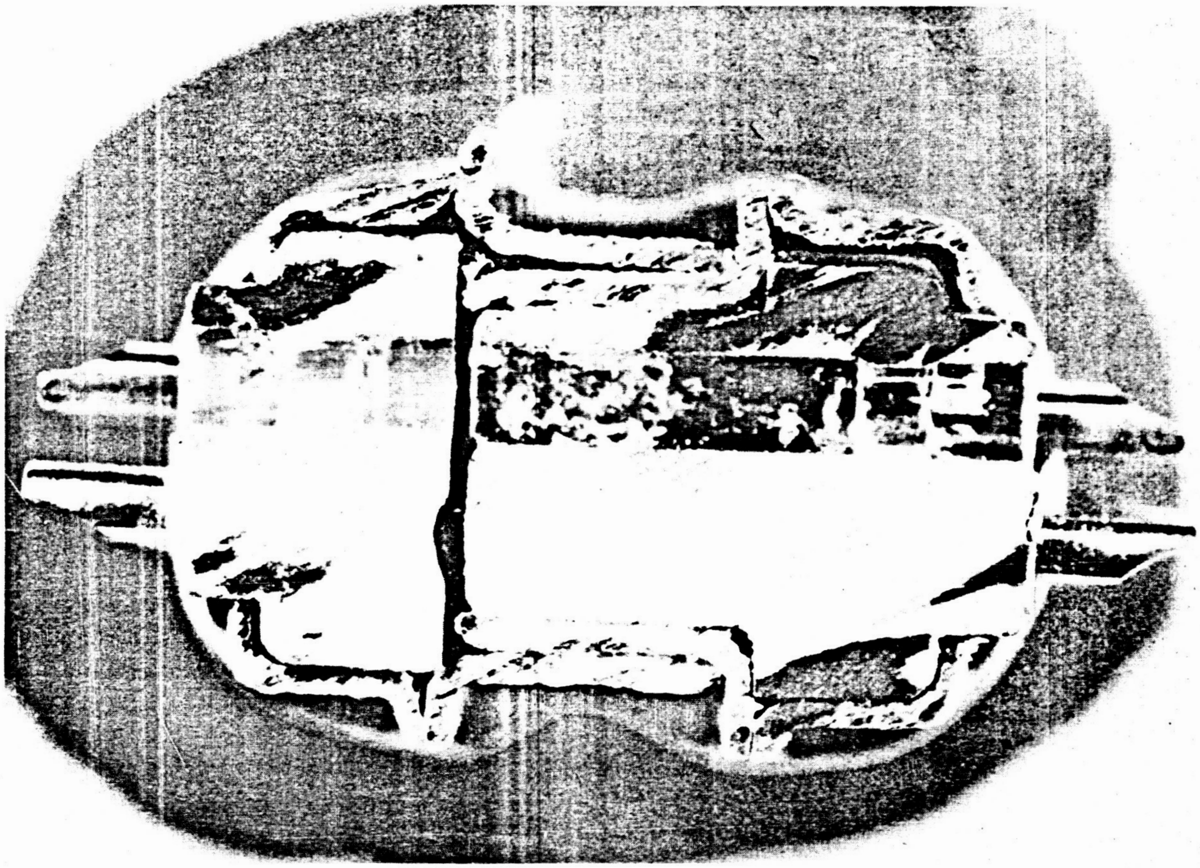

Figure 12. Cross-Section of Mated Connector Halves Shown in Figure 11, Disclosing Space Into Which Metallic Whiskers Can Grow.

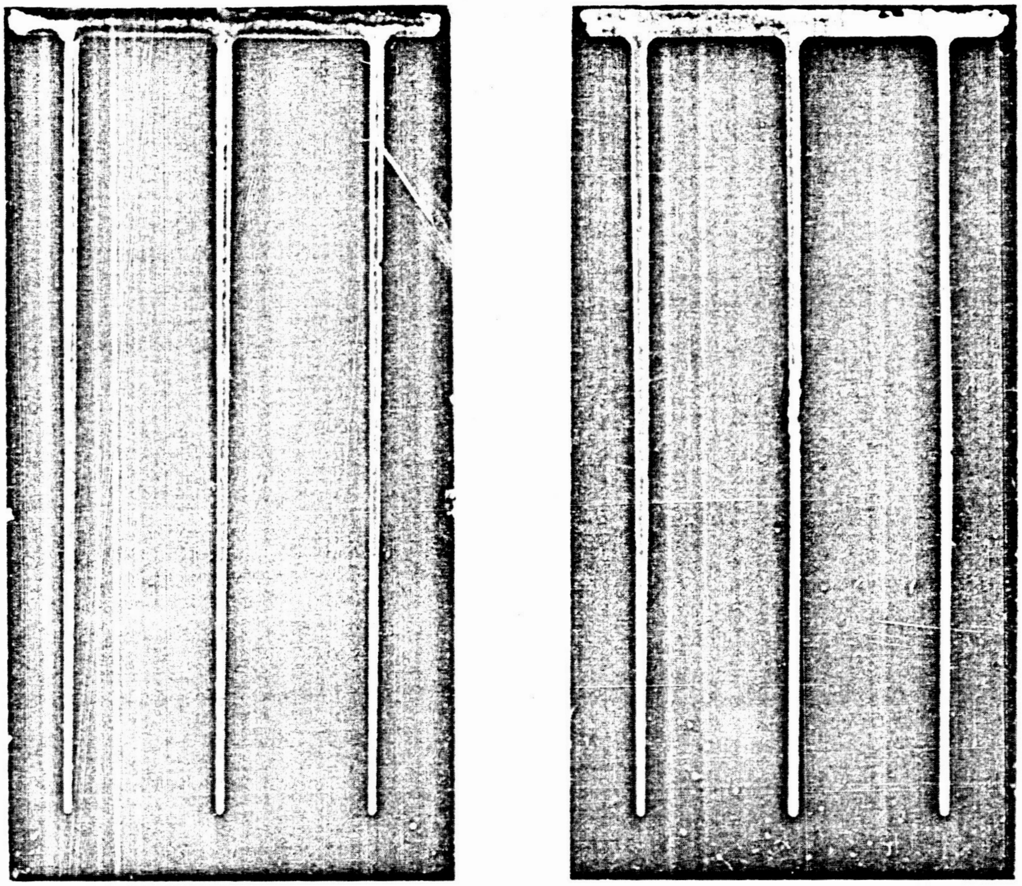

Figure 13. Top Side of Solar Cells. Bright Bands are Contact Strips (Along Edge) and Collector Grids.

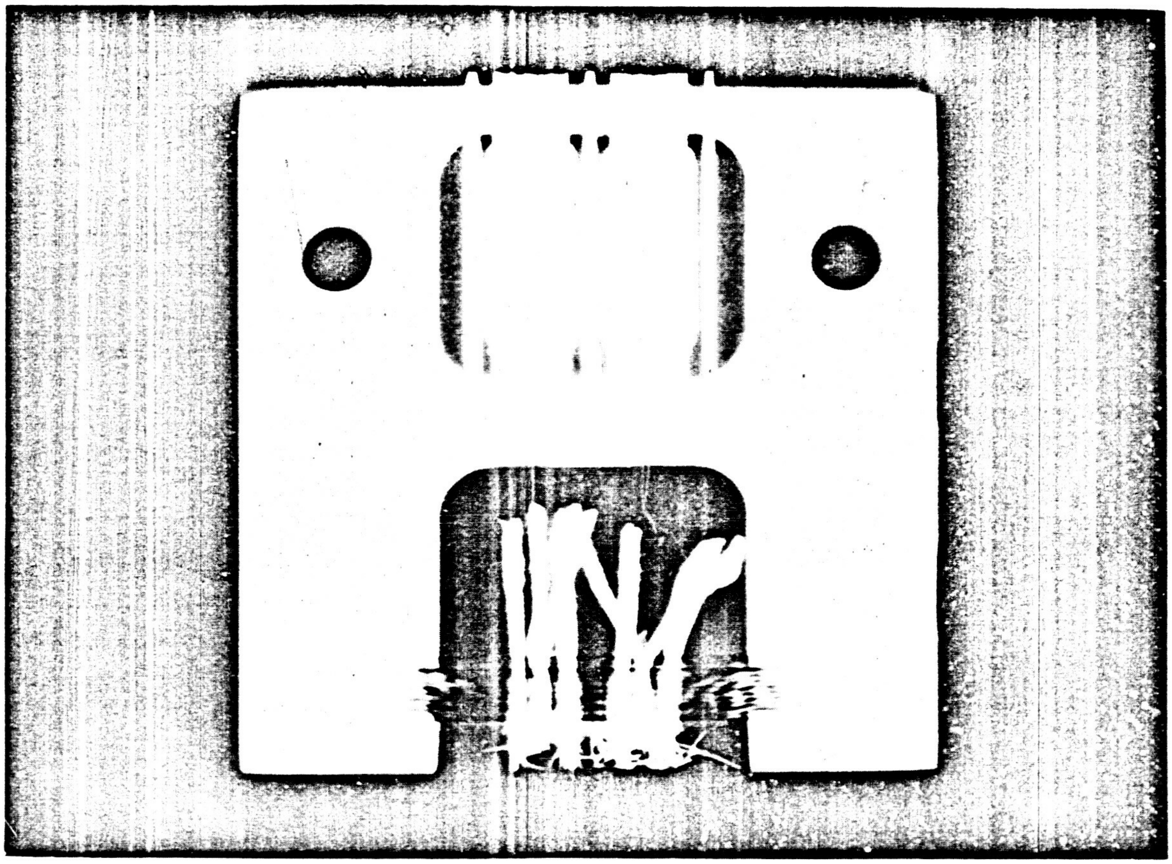

Figure 14. Radiograph of Tape Recorder Head. Failures Were in the 2-Mil Dia. Wires Connected to the Leads, Seen at the Bottom.

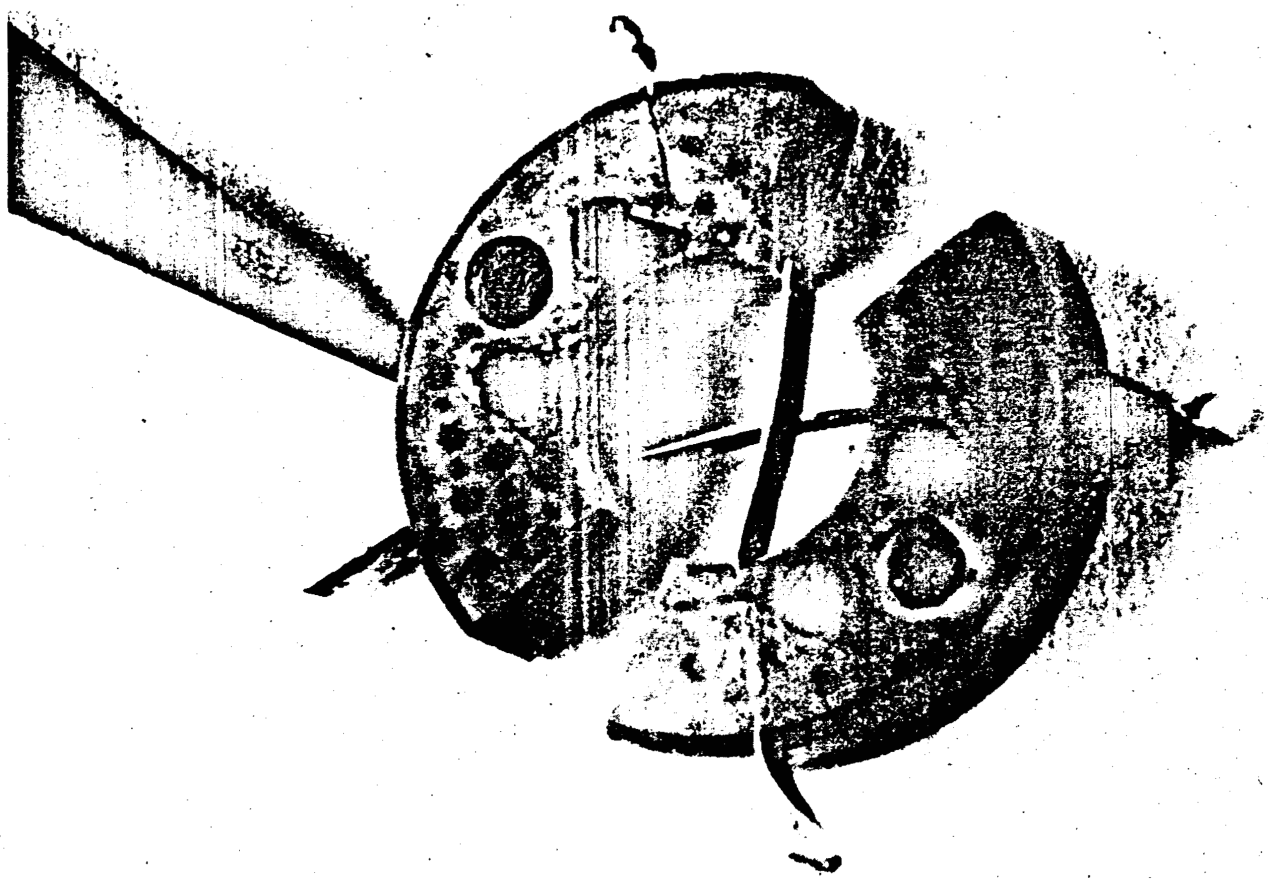

Figure 15. OGO Horizon Scanner Pivot Showing Broken Cu-Be Flexure Spring. Dark Object at Top of Picture is Pencil Point.

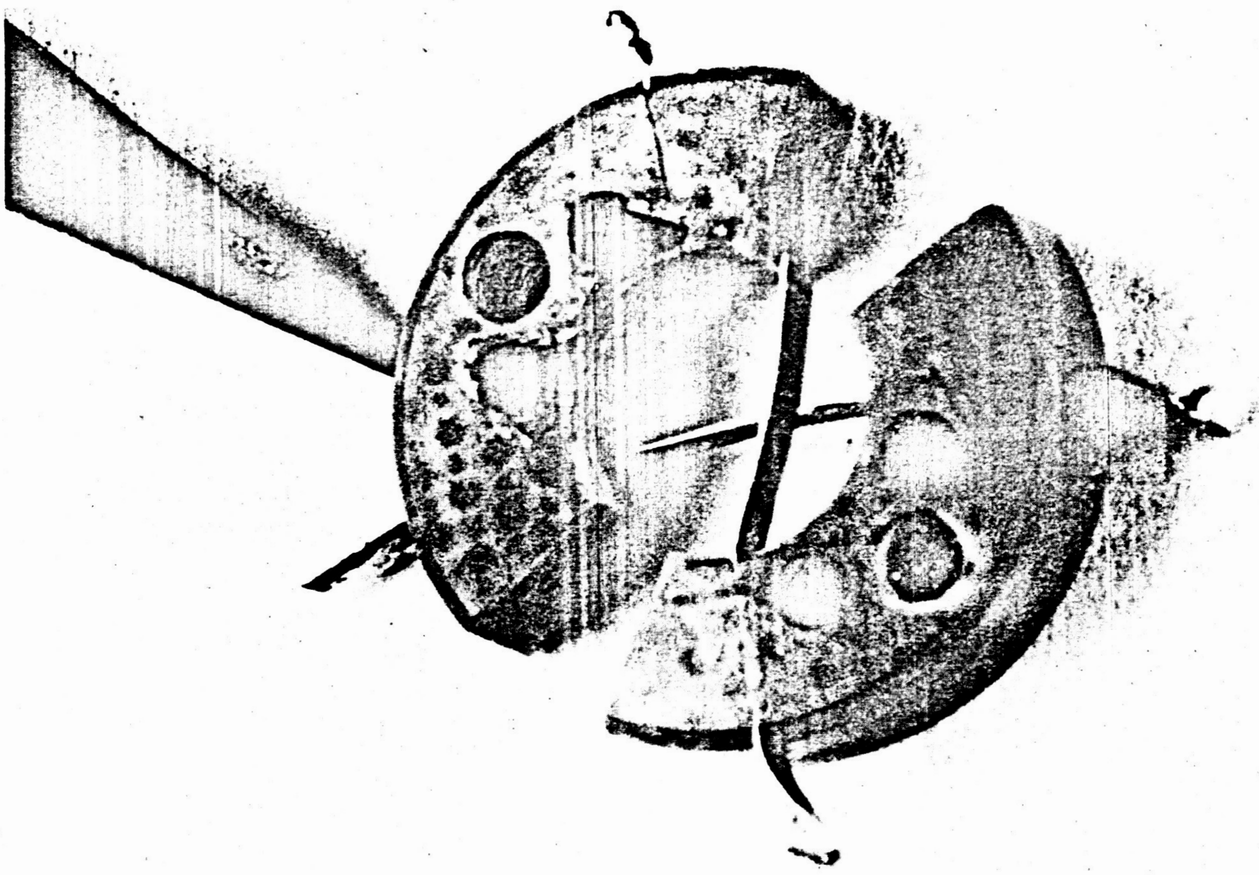

Figure 15. OGO Horizon Scanner Pivot Showing Broken Cu-Be Flexure Spring. Dark Object at Top of Picture is Pencil Point.

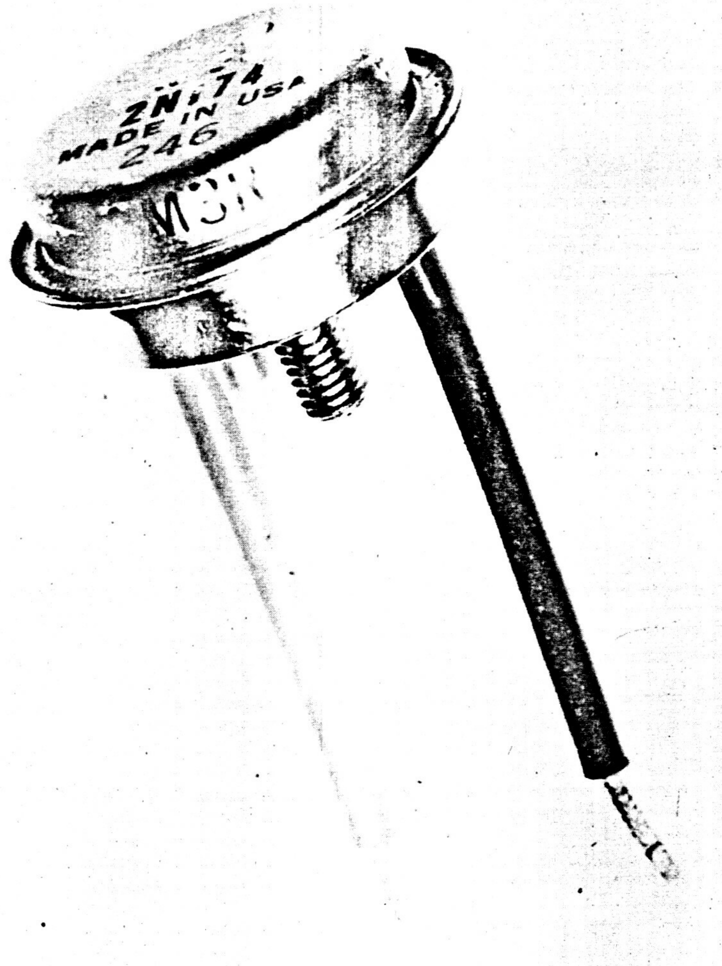

Figure 16. Hermetically Sealed Transistor, Typical of Many Used on Satellites.

Figure 17. Interior View of Transistor Seen in Figure 16.